

Music Chills:

The Eye Pupil as a Window to the Soul of Music

Lise Mette Eidet



Master of Philosophy in Psychology

Department of Psychology

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Summary

Author: Lise Mette Eidet

Title: Music Chills: The Eye Pupil as a Window to the Soul of Music

Supervisors: Professor Bruno Laeng and Research Fellow Unni Sulutvedt

Background: The aim of this study was to investigate the relationship between pupil diameter and the experience of so-called music chills. Earlier studies have reasoned that musical stimulation has measurable effects on both behavior and brain chemistry. The theoretical background for studying pupillary reactions when experiencing music chills was based on the known relationship between the activation of noradrenaline (NE) and changes in pupil size as well as indications that the NE system is involved in music chills. The hypotheses of the current study are following: 1) the participants will report chills more to their own selected songs than their control (i.e. selected by others) songs. 2) the participants' pupils will dilate more often when they experience chills to their own chosen music than to the control pieces, and that 3) the pupils will significantly dilate around the time they indicate they experience a chill.

Methods: Responses to a questionnaire about the experiences with music chills were collected from 52 participants (mean age = 31.98; range = 21-59) that also completed the listening-experiment in the laboratory. They were each requested to choose three experimental songs, that they knew would provoke chill experiences. All participant were matched with another person of the same sex and age, as each participant's songs were used as their match's control trials. The study also included an active and a passive condition to compare pupils when focusing on the chills' experience versus simply listening.

Results: As expected, participants experienced significantly more chill episodes to their own music choices than the controls'. Pupillary responses to active versus passive listening conditions were strongly correlated, suggesting that similar experiences may occur when an explicit response is required or not. Pupils reacted more to the experimental songs than control songs also in the passive listening condition and at the time the participants had indicated (in the active condition) that a chill occurred. This confirmed that pupillary responses can index the presence of chills also without an explicit response, although having to make a response may increase the impact of the chill experience. An unexpected finding

was that, during passive listening, pupils' responses related to chills were significantly larger only for the first songs, suggesting that fatigue or habituation may have influenced the participants' physiological reactivity to chills.

Conclusion: There is a relationship between pupil diameter and the experience of music chills, as pupils dilated when participants indicated when they were having the experience. The present findings also strengthen the relationship between the activation of NE, indexed by pupil size and chills. Chills are therefore measurable through correlated psychological measurements. Despite that the order of the songs and the length of time played an important role (especially during passive listening), control songs never showed stronger effects than the experimental songs, which speaks for the subjective quality of the experience. The present results extend and support previous studies of chills and music.

Note: The experiment was based on an idea by Bruno Laeng, and all data were collected by the student under his supervision and that of Unni Sulutvedt.

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Abstract

Strong emotional and bodily experiences with music are a very complex phenomenon that may be best observed in terms of the involuntary bodily reactions that can accompany strong musical experiences. Based on the relationship between the activation of noradrenaline (NE) and changes in pupil size, there is a theoretical ground for studying pupillary reactions when experiencing music chills. In the present study, participants listened to self-chosen songs versus control songs chosen by the other participants, since findings from previous studies indicated that self-chosen songs were more effective in evoking chills during listening. The experiment included a passive condition, and an active condition where participants made key presses to indicate when experiencing chills. The present findings supported the hypothesis and strengthen the relationship between the activation of NE, seen as changes in pupil size, while experiencing chills. Control songs never showed stronger effects than the experimental songs, which speaks for the subjective quality of the experience. Interestingly, physiological responses to chills decreased with listening time. The present results extend and support previous studies of chills and music.

1 Introduction

Strong emotional and bodily experiences with music are a very complex phenomenon that is influenced by many different interacting factors. Individuals react differently to variations in music type, and even the same musical piece can give different reactions from time to time. These experiences are difficult to describe with words, and may be best observed in terms of the involuntary bodily reactions that can accompany strong musical experiences. In 1968 Maslow made a term for such strong experiences, called “peak experience”, which he rated as the highest level in his famous hierarchy of needs. The peak experiences were summarized by respondents as “the most wonderful experiences of your life, happiest moments, ecstatic moments, and moments of raptures, from being in love or listening to music” (see also Gabrielsson, 2011). Maslow meant that a “peak experience is good and desirable, there is a complete loss of fear, anxiety, inhibition, defense and control. An emotional reaction in the peak experience has a special flavor of wonder, of awe, of reverence, of humility and surrender before the experience as before something great” (...). Apparently, the two most common ways of obtaining such peak experiences is through either sex or music (Gabrielsson, 2011, pp 548).

Panzarella (1980) extended Maslow’s investigations, and collected reports of intense joyous experiences while listening to music or looking at visual art. The sample of this study consisted of 103 persons, where half of them described musical experiences and the other half experiences with other arts. Four major factors were revealed from the analysis: 1) renewal ecstasy or an altered perception of the world (e.g. "The world is more beautiful than ever before"). 2) Motor-sensory ecstasy - physical responses, changes in heart rate, breathing, posture, or locomotion, presence of shivers, chills, etc., and quasi-physical responses (e.g. feeling high, floating). 3) Withdrawal ecstasy - loss of contact with both the physical and social environment. 4) fusion-emotional ecstasy - merging with the aesthetic object. Interestingly, motor-sensory ecstasy and fusion-emotional ecstasy were more pronounced in music reports, while renewal ecstasy was prominent in visual art, and withdrawal ecstasy were pronounced in both music and art (Panzarella, 1980).

Remarkably, music can evoke both basic and complex emotions, and emotions to music share many psychological mechanisms with other emotional reactions (Juslin & Västfjäll, 2008). Music can evoke changes in psychological arousal (autonomic and endocrine activity), subjective feelings (experiencing sadness, to be happy etc.), and can also have effects on motor expressions (dancing, smiling, tapping the rhythm with the foot). In fact,

even though a person feel true sadness by sad and melancholic music, this music can be used as a rewarding experience. The experience can then be perceived as fun, and activates reward circuits in the brain (Juslin & Västfjäll, 2008).

A seminal initial project on how people can be affected by music was called “Strong Experiences with Music” (SEM), and was loosely based on Maslow’s “peak experiences” (Gabrielsson, 2011). These experiences included physical, behavioral, perceptual (auditory, tactile, visual, etc.), cognitive (expectancy, absorption, change experience of situation, loss of control, memories, thoughts etc.), social, existential, or transcendental feelings, quasi-physical sensations and powerful emotions. Both positive and negative. All participants were volunteers with different age, education, musical experiences and taste in various genres of music. The most reported feelings (from the participants’ self-reports) were first of all tears (24%), chills or shivers (10%), and gooseflesh (5%). The physical responses also included indices of autonomic arousal, like racing heart rate, muscle tension, and changes in body temperature and breathing (Gabrielsson, 2011). Such strong experiences with music suggest a vocabulary that is prone to oversimplifying the experiences, while being resistant to generalization.

1.1 Music Chills

Music expectation has been a central phenomenon in music and emotions, and the traditional emphasis on expectation may be traced in part to some of the unique properties of music, compared to other arts. It has been suggested that in other kinds of arts, emotions are evoked through representations of common emotional displays, such as portraiture, sculpture, drama, film, and dance. This is because human body language and facial expressions may evoke particular affective states (Huron & Margulis, 2011). Despite this, music has been described through history as the most emotional of the arts. For example if a person wants to change mood, or seek nostalgia, they often choose music. Scientists have understood that psychological time plays an essential role in musical experience (...). Surprise, anticipation and delay are important aspects of musically evoked affect. Time in music permits a listener to engage with a stimulus in an active, predictive way, which allows dynamic fluctuations in affective responses (Huron & Margulis, 2011).

A musically induced affect that shows close links to musical surprise has been in popular language called “chills”, “thrills” or “frissons” (Harrison & Loui, 2014). All three of the names are identifying significant and easily testable parts of such “transcendent” moments

(Harrison & Loui, 2014). An example of a description of the experience is an intense peak of pleasure, like a rapture and total absorption or focus in the musical moment. Importantly for the present study, these feelings can also result in felt bodily reactions that may vary remarkably from person to person but that tend to reach peak intensity at precise moments during the musical listening. These reactions can include weeping and/or skin sensations, like goose bumps, and changes in the muscles of the body (e.g., shivers down the neck and back, that may spread down the limbs and body) as well as in the muscles of the face (like a flow of relaxation). Some individuals can also feel their heartbeat change, and someone may feel “merging” into the music (Panksepp, 1995).

Panksepp (1995) found in his large survey of college students that many people believed that happy music was more influential than sad music to evoke chills. He also found through correlation studies that when the students were listening to different musical pieces, the chills were related to perceived emotional contents and especially strong relationships with sadness, which is the opposite of what the participants expected. Also, the female participants reported more chills than males.

Surprisingly, intense emotional responses to music have been observed infrequently in music psychology research, probably because in most experiments, the researchers had chosen the songs or pieces used as target stimuli, therefore reducing the chance that a participant’s most-moving pieces would be included in the study. Hence, when investigating these responses, it seems important to let each participant choose songs or musical pieces that are actually capable to evoke chills and deep emotions, in each specific individual included in the study (Rickard, 2004). This obviously complicates the experimental design of a study, because it means that the musical characteristics of the experimental conditions cannot be kept constant across participants; yet it is more likely that the emotions elicited across participants would be similar, despite the ample variation in the inducing stimuli (Rickard, 2004). Indeed, Panksepp (1995) confirmed that participant-selected music, describing as ‘especially motivating’ elicited a greater number of bodily ‘chills’ than other musical pieces.

To investigate who usually got chills and why, Nusbaum et al. (2014) studied undergraduates with an “experience sampling method” through their own cellphones. The questions had yes/no options, like “Are you listening to music right now?”, “Do you have emotional chills or goose bumps?”, and “Did you choose this music?” They were also queried about their current mood, with a 7-step scale; e.g. about how happy, sad or worried they felt at the moment. If they were listening to a self-chosen musical piece, they were asked if the music had special meaning to them, and if they were listening closely to the music (1-7 scale).

They also had to answer if they were alone or with other people while listening. The results showed that the context and the emotional state were quite important; people were significantly more likely to get chills when they chose the music themselves, and when they were listening closely to the music. A musical piece's special meaning was only slightly significant, but associated with a higher likelihood of getting chills (Nusbaum et al., 2014). Participants were more likely to get chills when they were happy or sad, but not while worried. Being alone did not significantly increase the experience of chills while listening to music, but this varied from person to person (Nusbaum et al., 2014).

An earlier study of personality traits by Silvia & Nusbaum (2011) used a measure of chills in adults, and included the Big Five domains, and their music preferences, habits, and experiences. Among the results in this study: Openness to the chill experience was the strongest predictor for occurrence of chills during musical listening. Openness predicted the relevance of music in someone's life, like the number of hours per day they listened to music, and whether they played an instrument. Participants' engagement explained the effect of personality on chills, but genre preferences did not predict chills (Silvia & Nusbaum, 2011).

Likewise, Grewe, Nagel, Kopiez and Altenmüller (2007) studied distinct acoustical and musical structural elements related to reported chill reactions. Participants were asked what kind of elements they found most pleasurable. Examples were the beginning of a piece, entry of instrumental or human voice, volume/volume changes, melody, theme or motive, tempo, rhythm, contrast of two voices, and harmony (Grewe et al., 2007). The participants seemed to react the most to musical patterns, especially to the entry of a voice and changes in volume. Chill reactions were evoked by musical preferences and listening situations.

Recently, neuroimaging research has come to the fore in the study of music-related peak experiences. In a seminal study by Blood and Zatorre (2001), participants listened to self-selected songs that gave them chills while lying in an MRI scanner. The method has the potential to reveal the underlying neural mechanisms that support the occurrence of chills and positive emotions. Participants did experience chills when listening to their own music choices, but not when they listened to control songs. It was found that, during chills, blood flow increased in the brain regions associated with reward, emotion and arousal (e.g., ventral striatum, dorsomedial midbrain, amygdala, hippocampus, cortex and orbitofrontal prefrontal cortex). Interestingly, music proved to have the same effect in a network of the brain that is related to biologically significant and euphoric stimuli, such as food, sex and drugs. It is also found in other studies, for example by Harrison and Loui (2014) that people react more strongly to music that they recognize than completely unknown music. Researchers have

speculated that one reason people may experience an affinity for chills-inducing music is that, when listening to beloved pieces of music, one is under a dopaminergic system-based expectation that makes one want more of the music, in a manner that is similar to becoming "addicted" to it (Blood & Zatorre, 2001). Ironically, "sex, drugs and rock'n'roll" seem to depend on the same brain network.

The rewarding aspects of music listening and the relation to emotional arousal was investigated by Salimpoor, Benovoy, Longo, Cooperstock, and Zatorre (2009). This study included 26 participants who listened to self-selected songs versus neutral music that was selected individually. They investigated whether there was a systematic relationship between increases in pleasure states and physiological indicators of emotional arousal. This included changes in body temperature, heart rate, respiration, electro dermal activity, and pulse. Participants also used real-time key presses to point out the exact time for their chills (Salimpoor et al., 2009). Results regarding musical pleasure showed that even without the experience of chills, pleasure was directly associated with increases in psychophysiological arousal. The participants often experienced 'high pleasure' that did not give them full-blown chills, but physiological signals indicated increase in autonomic nervous system arousal to these episodes (Salimpoor et al., 2009). When the chills were experienced, there were characterized by extreme increases in autonomic nervous system arousal that were greater than those relating to 'high pleasure'. For only those individuals who did experience chills, these were characterized by peak autonomic nervous system arousal, demonstrating extreme sympathetic nervous system activity (Salimpoor et al., 2009). The measures of heart rate, respiration rate, electro dermal activity, skin temperature, and pulse were all consistent with a gradual and highly significant arousal during the chills, confirming that these are typically experienced at the climax of the pleasurable responses. This is in line with earlier studies (e.g. Blood & Zatorre, 2001). Importantly, individuals who did not experience pleasure or chills also showed no significant increases in emotional arousal (Salimpoor et al., 2009).

1.2 The Ventral Striatum and Music

Although one of the present study's goals is to confirm, indirectly via pupillary responses to chills, the involvement of the norepinephrine system and locus coeruleus of the brain in chills experiences, it is relevant to mention another key brain structure and neurotransmitter system for peak experiences that has been identified by neuroimaging. The nucleus accumbens (NAc) is a region in the basal forebrain rostral to the preoptic area of the

hypothalamus, which has been clearly involved in intensely pleasurable responses to music. The nucleus accumbens is a part of the ventral striatum, which is a part of the basal ganglia, and has a significant role in many cognitive processes, like motivation, pleasure, reward, reinforcement and addiction (Brodal, 2013). The NAc is innervated by dopaminergic brainstem neurons (located mainly in the ventral tegmental area of the midbrain) and appears to play a role in selecting and directing behavior in response to specific and motivational stimuli, as well as in motivation and rewarding such behavior (Nicola, 2007). It also plays an important role for the learning, and execution of actions (Koelch et al., 2011). The NAc and the ventral striatum shows greater activity for immediate rewards, whereas the dorsal striatum, shows greater activity for future rewards.

Brown, Martinez, and Parsons (2004) performed a PET-scan study where non-musicians passively listened to unfamiliar instrumental music that actually elicited strongly pleasant feelings. The results showed activation of the ventral striatum during listening to two unfamiliar pieces with a resting condition as control. Other active areas were observed in the subcortical cingulate cortex, the anterior insula, the subcallosal cingulate gyrus, prefrontal anterior cingulate, retrosplenial cortex, nucleus accumbens and the posterior part of hippocampus (Brown et al., 2004). These findings are the first observations of spontaneous responses that elicit positive emotions and activations in limbic and paralimbic areas, when people are passively listening to unfamiliar music, in the same way as with familiar music (Brown et al., 2004).

Menon and Levitin (2005) observed activation of the ventral striatum (the fun centers) when participants were listening to pleasant music in an fMRI-scanner. The results showed activations in the ventral striatum and the ventral tegmental area (VTA) when the musical pieces sounded normal and pleasant, in contrast to when the musical pieces had parts that were unpleasant, with disturbing noises (Menon and Levitin, 2005)

Music can arouse feelings of euphoria and craving, like rewards that involve the striatal dopaminergic system. Dopamine release during peak experiences was studied by Salimpoor, Benovoy, Larcher, Dagher, & Zatorre (2011), through positron emission tomography (PET) scanning and functional magnetic resonance imaging (fMRI). Participants provided ten instrumental pieces of music in any genre they liked, that evoked chills and intense pleasure. Control stimuli were selected for each participant using one person's pleasurable music as another person's neutral music. Efforts were made to ensure that the musical pieces were as evenly distributed as possible, using a scale from 1-10 for rating each other's match songs before doing the experiment. Participants rated their chills by button

presses when experiencing chills, while listened to their chills-inducing music. The PET scanning combined with psychophysiological measures of autonomic nervous system activity, led to findings of endogenous dopamine release in the striatum at peak emotional arousal during music listening (Salimpoor et al., 2011).

1.3 Pupillometry

Changes in pupil sizes have been noted and believed to be indicators of emotional arousal for a long time (Granholm & Steinhauer, 2004) and they have linked to activity of the locus coeruleus and norepinephrine system of the brain (Aston-Jones & Cohen, 2005). The use of pupillometry in psychology is at least a fifty year old method (Laeng, Sirois, & Gredeback, 2012). Small changes of fractions of a mm can be captured precisely with modern infrared eye-trackers and today it is possible to resolve better than 0.025 mm in diameter on individual measurements, also at sampling rates of 60 Hz (Granholm & Steinhauer, 2004). Importantly, by measuring pupillary changes to stimuli, it is possible to measure spontaneous reactions that people are not able to control themselves (Laeng, Sirois, & Gredeback, 2012). Pupils cannot be controlled at will (as we can for example blink our eyes) and they can be controlled indirectly only people mentally imagine something that normally would have changed pupils, e.g., erotic stimuli or even imagining something dark or bright (Laeng & Sulutvedt, 2014). In a study by Lubow & Fein (1996) about visual guilty knowledge, they successfully used pupillometry as a technique to find out that people's pupils would change in size when they were lying about something (Lubow & Fein, 1996).

Earlier results from pupillometry studies using picture stimuli, have shown that pupils dilate more when participants (both males and females) are presented with sexually related pictures, rather than with neutral pictures. Pictures of babies also made pupils dilate in female participants (Hess & Polt, 1960). Studies also found that heterosexual females display pupil dilation to nude females and heterosexual males to nude males, and not just to the opposite sex. A replication study based on those results where heterosexual males and females viewed pictures of nude females and males, and clothed females and males, confirmed the probability that pupillary response to nudity is more attributable to the novelty of the images, than to their sexual nature (Aboyoun & Dabbs, 1998). The pupil diameter was for both females and males, largest when they were viewing nude males. This might be because the sight of nude men is more unfamiliar in this female body focused society (Aboyoun & Dabbs, 1998).

A recent study with a large sample of participants (N= 325) by Rieger and Savin-Williams (2012) has confirmed that self-reported sexual orientations (i.e., heterosexual, homosexual, bisexual) of both sexes corresponded with systematic pupil dilations to erotic stimuli that differed between men or women. Specifically, among men, substantial dilation to both sexes was most common in bisexual-identified men but, among women, substantial dilation to both sexes was most common in heterosexual-identified women. In other words, bisexual men had bisexual dilation patterns, while homosexual women had male-typical dilation patterns. Moreover, stimuli may not need to be labeled as “sexual” either in order to observe changes of the pupil related to changes in sexual motivation, as a study by Laeng & Falkenberg (2007) showed by measuring women's pupillary responses to facial portraits of their partners (i.e., sexually-significant others) during their hormonal cycle. Specifically, they found that pupil diameters increased during the follicular (ovulatory) phase of the cycle compared to the luteal or menstrual phases of the cycle and only in those women that were not using the contraceptive pill.

In an fMRI study by Demos, Kelley, Ryan, Davis and Whalen (2008) the subjects' pupils dilated when seeing manipulated pictures of people with larger pupils than normal. The subjects were not aware of the manipulations or their own reactions. It was also found increased activity in the right amygdala, the left amygdala and the substantia innominata, which suggested a role for the amygdala in the detection of pupil size (Demos et al., 2008). All stimuli, also other than visual can have clear effects on pupils' size; e.g., both pleasant or unpleasant tastes of liquids (Hess & Polt, 1966), as well as auditory stimuli that are surprising or pleasant/unpleasant.

1.4 Locus Coeruleus and Norepinephrine

Changes in pupil size occur through neural mechanisms in parasympathetic oculomotor complex, or Edinger-Westphal nucleus of activity and in the locus coeruleus, which is the main system of noradrenergic arousal (Laeng, Sirois, & Gredeback, 2012). The locus coeruleus is located on each side of the pons and might be most known for its role in anxiety, depression and panic disorder.

Locus coeruleus (LC) is the main hub of the neurotransmitter Norepinephrine (NE), which modulates the activation of the brain (e.g. whole cortex). In research it has been found that there is a link between the pupillary response and activation of LC and NE system (Aston-Jones & Cohen, 2005). Also, pupil dilation by psychological stimuli is controlled by

the sympathetic limb of the autonomic nervous system by the posterior hypothalamic nucleus, which can make the iris dilate (Privitera, Renninger, Carney, Klein, & Aguilar, 2010).

According to Aston-Jones and Cohen (2005) there are two different modes of LC activity. One is the phasic mode, which is associated with lower baseline NE release from the LC, and high phasic firing in response to demanding tasks. This is also associated to increased engagement and performance on tasks. The other mode is the tonic mode, with elevated baseline NE firing rate for easier tasks, and this mode consequently renders the system more sensitive to task irrelevant stimuli (Gabay, Pertzov, & Heni, 2011). This might enable a change in behavior in response to more valuable reward opportunities (Aston-Jones & Cohen, 2005). The two modes have been studied through animal studies, for example with monkeys (Usher, Cohen, Servan-Schreiber, Rajkowski, & Aston-Jones, 1999), as well as human studies. The findings suggest that LC may play a role in attentional modulation and goal-directed behaviors, but also in experimental behaviors (Usher et al., 1999). Many studies have suggested that pupil size can be used as an indirect marker of activity within the LC-NE system in humans (Privitera et al., 2010).

The LC-NE system is also important for example in memory retention, with retrieval of recent information dependent on noradrenaline's modulatory effects (Sara, 2009). There are correlations between pupillary response and LC activity during memory tests (Sterpenich et al., 2006). In an fMRI study combined with pupillometry, participants were exposed to neutral faces in neutral and emotional contexts. Emotional reactions were measured by increased pupil dilation during successful retrieval of neutral events, learned in an emotional context. This was found to correlate with LC activity. There was no significant LC activation during retrieval when there had not been a pupil diameter increase during learning. This suggests a link between the LC and pupil dilation (Sterpenich et al., 2006). Another example regarding memory and pupillometry is the study of patients with brain damage by Laeng et al. (2007). Patients showed deficits in explicit memory recognition, but their pupil size increased when watching novel pictures compared to pictures that were previously presented. This confirms that novel stimuli have the ability to index the memory of a picture or item, through automatic pupil responses, and the pupil can differentiate between old and new pictures with a memory component (Laeng et al., 2007; Papesh, Goldinger & Hout, 2011).

This link between pupillary response and LC activity suggests that the use of pupillometry allows obtaining information on attention, emotion, and memory (Sara, 2009). Importantly for the present research, animal studies on young chicks have indicated that musical stimulation had measurable effects on their behaviors and brain chemistries,

especially increased turnover of norepinephrine (NE) in the brain (Panksepp & Bernatzky, 2002).

1.5 The Current Study

The aim of this study was to investigate the relationship between pupil diameter and the experience of music chills. At the basis of the present study is the proposal by Panksepp & Bernatzky (2002) based on animal studies that musical stimulation has measurable effects on both behavior and brain chemistry, specifically increased turnover of norepinephrine (NE). Consequently, the theoretical ground for studying pupillary reactions when experiencing music chills is based on the relationship between the activation of norepinephrine (NE) and changes in pupil size, and there is a link between emotional responses to sounds and norepinephrine (NE). If confirmed, this would strongly constrain Harrison and Loui's (2014) point that the strong emotions to music, like chill responses, may not be testable other than through self-report. Nusbaum et al. (2014) suggested in their conclusion that future approaches in selection of musical stimuli used to elicit human bodily responses (like chills) to music, may achieve important knowledge and a fuller view of cognitive and social behavior about the unique experiential dimensions of music.

In the current experiment, we used self-chosen songs versus control songs, since previous studies found that self-chosen songs were more effective in evoking chills during listening (Panksepp, 1995; Blood & Zatorre, 2001). All participants were tested in each condition, using a within-subject repeated-measures design. The experiment included an active condition with key presses when experiencing chills, and a passive listening condition of the same songs.

The hypotheses of the current study are the following: 1) the participants will report chills more to their own selected songs than their control songs. 2) the participants' pupils will dilate more often when they experience chills to their own chosen music than to the control pieces, and 3) the pupils will significantly dilate around the time they indicate they experience a chill. If the predictions stated above are confirmed, our findings will confirm that music chills and emotionally peak experiences have a measurable physiological effect, and this can be specifically linked to increased turnover of norepinephrine (NE) in the brain.

2 Methods

2.1 Participants

There was a total of 52 participants (mean age = 31.98; range = 21-59) that completed the experiment, which included 24 males (mean age = 33.04; range = 23-59) and 28 females (mean age = 31.07; range = 21-57) with normal or corrected to normal vision. The participants were recruited among friends, acquaintances and students at the University of Oslo (Department of Psychology). Two additional participants were excluded because of poor pupil calibration and no matching control person. The participants were Norwegians or English speakers. They all signed a written informed consent before taking part in the experiment.

2.2 Materials and Apparatus

At the beginning of the experiment, all participants filled out an online questionnaire with questions and a checklist about their experiences with chills (see Appendix A). These questions were based on previous research literature on the topic (Panksepp, 1995). They were requested to choose three “songs” each that they knew would (much likely) provoke chills in one form or another. Three songs (six in total) seemed to constitute a sufficient number of trials for each participant. A larger number of choices would have made testing impractical in terms of testing time and, possibly, fatigue or habituation effects. They were also asked to choose songs that lasted for a maximum of five minutes.

The pupillary data were recorded with a Remote Eye Tracking Device (RED, SMI-SensoMotoric Instruments, Teltow, Germany). The eye movements, fixations and pupillary responses were collected with I-View Software (SMI). The pupil diameter of both eyes was measured at a sampling rate of 60Hz. The RED can operate at a distance of 0.5-1.5 m. This device has two sources of infrared light from an infrared light sensitive video camera, placed under the monitor frame. According to SMI, the RED system can detect changes as small as 0.0044 mm. To optimize the recordings, participants were asked not to use their prescription glasses. Room lighting was kept constant.

All participants used a pair of headphones (Philips SBC HP840) when listening to the music in stereo. During the experiment, participants looked directly into a flat DELL LCD monitor, with a screen resolution of 1680x1050. Participants could give responses, during the active listening condition, by pressing a key on the PC's keyboard, placed in front of the

participant. Analyses of recordings were computed using the Be Gaze software from SMI, statistical software Microsoft® Excel, PASW® Statistics and Statview Software.

2.3 Procedure

Participants were tested with the same eye-tracking machine at the Cognitive laboratory in the Department of Psychology, University of Oslo. The chair was adjusted to the height of each participant at the beginning of each session. The session always started with an eye calibration procedure, and a subsequent validation procedure, by sequentially presenting points of fixation at four locations on the screen. The experimenter was present in the room throughout the whole session. Participants were requested to remain as still as possible during the experiment, and keep their eyes open focusing on a black fixation circle shown in the middle of the screen. The color used as background was a uniform and constant neutral grey color (ARGB: 255,166,166,166), also inside the circle. They were also told to avoid closing their eyes while listening, except for short eye blinks. If participants felt tired after a long period of fixation or had any questions, they could question the experimenter, but only after one of the songs was finished. Each participant was matched with another person of the same sex and similar age (plus or minus 1-2 years). Each "couple" heard their own songs as experimental chill-songs and the other person's songs as "control songs". They thus listened to six different songs, twice each, making a total of 12 trials.

The session began with an instruction slide and each trial was preceded by a slide that said they had to press next to continue. One of the chosen songs were played first and then interleaving every other song to the control songs. There were two versions of the test: 1) First, the participant listened to the songs, and then, in round two, the participant was asked to press the C key every time he/she experienced chills to the same songs. 2) The other version was the reversed order, i.e. the participant pressed the C key when experiencing chills in the first round and then only listened in the second round. One reason for using two versions was because some people could experience chills just the first time while others may get chills every time they hear their songs. These two versions switched randomly in the data collection process and therefore allowed also to counterbalance in the experiment the active versus passive listening conditions. Midway, the participants were offered to take a break to ensure that they were not too tired to get chills. The length of testing was different for each participant, due to the length of their chosen songs. All participants got to choose a gift (candy, etc.) after testing, as thanking for participating.

2.4 Pupil data preprocessing

The raw pupillometry data were preprocessed following similar procedures for all pupil data analyses. First the pupil data in video-pixels were aggregated in SPSS to find participants mean pupils for every song. The median pupillary size for each participant and for each repetition of a song was also computed to be used as a baseline.

Next step was to obtain pupil sizes around the time of a key press indicating a chill. The raw pupil data were converted through the IDF converter to find the pupil diameter, which in this case is expressed in millimeters. We selected one second before and one second after each key press as the time window within which chills-related pupillary changes were computed. This two seconds window was decided on the basis of previous studies showing that event-related pupillary dilation may begin about one second before a key press signaling an event and peak within one second after the response (e.g., Einhauser, Koch, & Carter, 2010). The same experimental songs were played in the passive condition. Therefore the same time windows selected from the active condition were identified in the eye-tracking data file of the passive condition, so as to provide a direct comparison of the occurrence of chills during active listening (i.e., while focusing on the bodily experiences and reporting them) versus just passive listening.

There was occasionally some overlap between time windows for participants that got a series of chills in a fast sequence; this time windows were joined together. Six participants were excluded from this analysis because of misunderstanding the passive task and pressing the key also during this condition; one participant failed to press the key at all (indicating no chill experience in the laboratory). The pupil data were then analyzed in Statview with a repeated-measures analyses of variance and regression analyses.

3 Results

3.1 Number of chills

The number of chills from all participants were counted. One participant was described as an outlier (i.e., the rate of key presses was more than 3 SDs higher than the rest of the participants) and was removed from the analysis. An initial repeated-measures analysis of variance (ANOVA) was conducted to compare the number of chills during listening to the experimental songs and the control songs. There was a significant main effect between the experimental condition (i.e., the songs chosen as chill-inducing) and the control condition (i.e., the songs chosen by the matched participant), $F(1, 51) = 28.908$, $p < .0001$, see Figure 1.

The means and standard deviations (SDs) for each song, aggregated over active and passive conditions, are presented in Table 1. Significant differences were found between experiment song 1 ($M=10.03$, $SD=17.55$) and the rest of the songs. There was a significant interaction effect between the songs, as the number of chills decreased from song 1 to song 3, but only in the experimental condition, $F(2, 102) = 7.72$, $p < .0008$, and the chill rate remained low for all of the control songs (see Figure 2).

Table 1

*Means and standard deviations for number of chills, Effect: condition*songs.*

Songs	N	Mean	SD
Experimental, Song 1	52	10,03	17,55
Experimental, Song 2	52	8,46	9,64
Experimental, Song 3	52	5,36	7,81
Control, Song 1	52	1,15	3,58
Control, Song 2	52	1,65	3,06
Control, Song 3	52	1,96	3,45

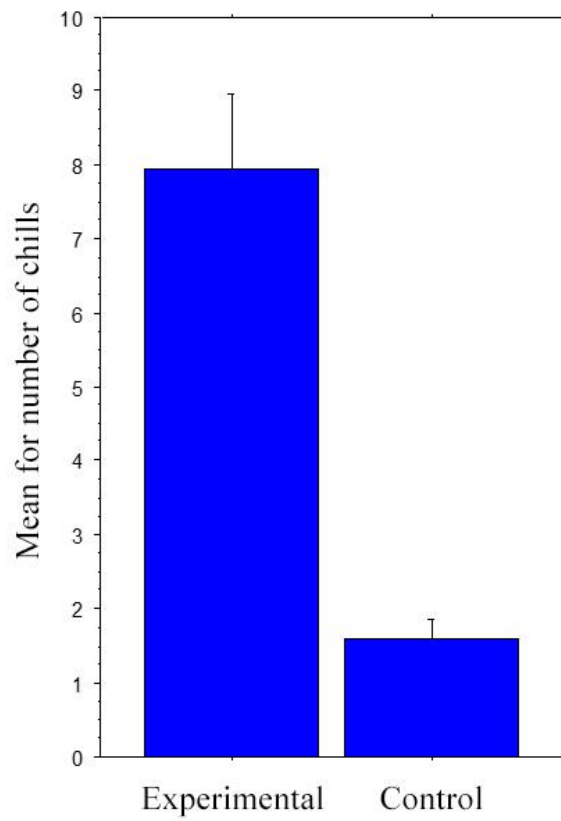


Figure 1. Mean for number of key presses while getting chills in experimental and control condition for all participants. Error bars represent ± 1 standard error.

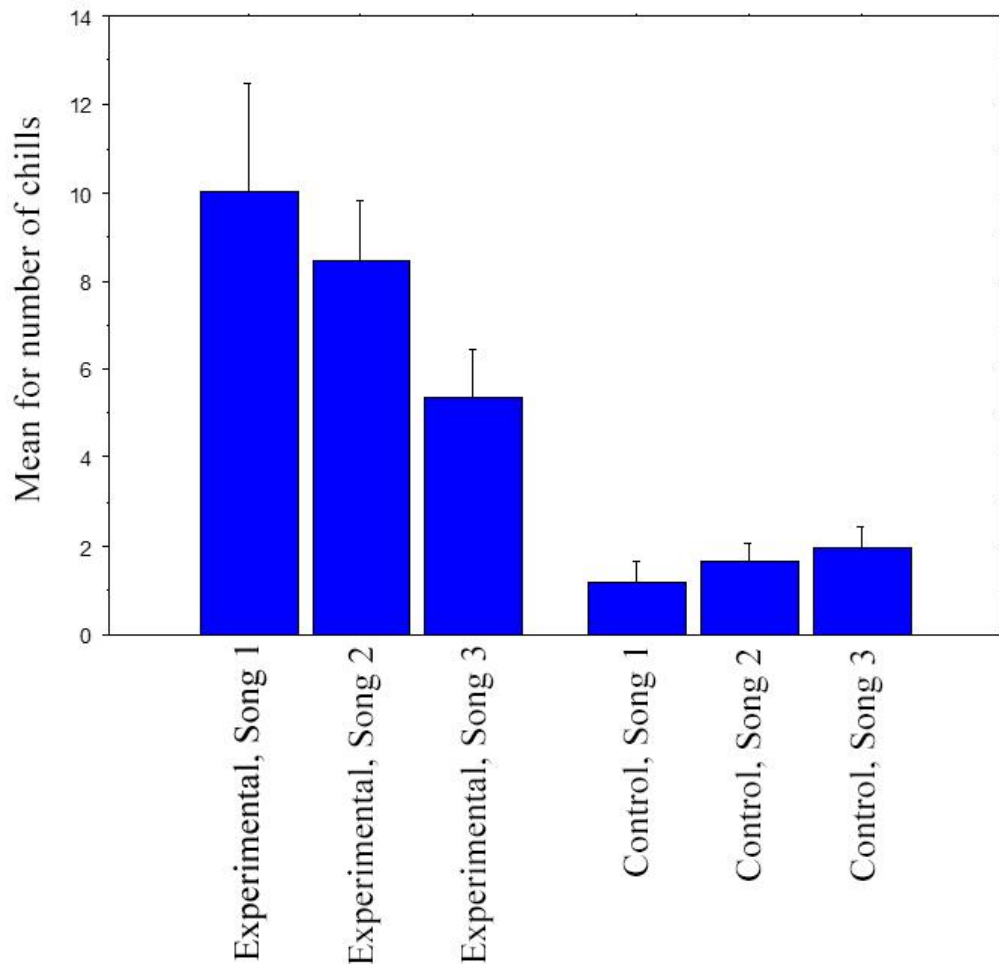


Figure 2. Interaction plot that shows the difference between number of chills for condition*song. Error bars represent ± 1 standard error.

3.2 Pupillary data

A repeated-measures analysis of variance was performed on all participant's mean pupils for every song all conditions. A preliminary analysis showed no significant sex differences, and sex as a factor was excluded from further analyses. The means and SDs are shown in Table 2. The ANOVA showed that there was a significant effect between experimental song and control songs, $F(1, 51) = 6.2$, $p < .02$ (see Figure 3). There was also a marginally significant interaction between songs (experimental, control) and response (active, passive), $F(2, 102) = 3.1$, $p < .05$. The mean pupil sizes were significantly larger in the experimental than control condition, as expected, for Song 1 and 2, but not for song 3, as verified by t-tests comparisons. Figure 4 illustrated these findings.

Table 2

Mean pupils (in pixels) for all participants in both experimental and control conditions.

Song * Response * Condition	N	Mean	SD
Song 1, Active, Experimental	52	13.31	2.30
Song 1, Active, Control	52	12.52	2.21
Song 1, Passive, Experimental	52	13.06	2.00
Song 1, Passive, Control	52	12.72	2.06
Song 2, Active, Experimental	52	13.46	4.68
Song 2, Active, Control	52	12.79	2.37
Song 2, Passive, Experimental	52	12.80	1.98
Song 2, Passive, Control	52	12.65	1.96
Song 3, Active, Experimental	52	12.98	2.41
Song 3, Active, Control	52	12.94	2.35
Song 3, Passive, Experimental	52	12.64	2.13
Song 3, Passive, Control	52	12.87	1.85

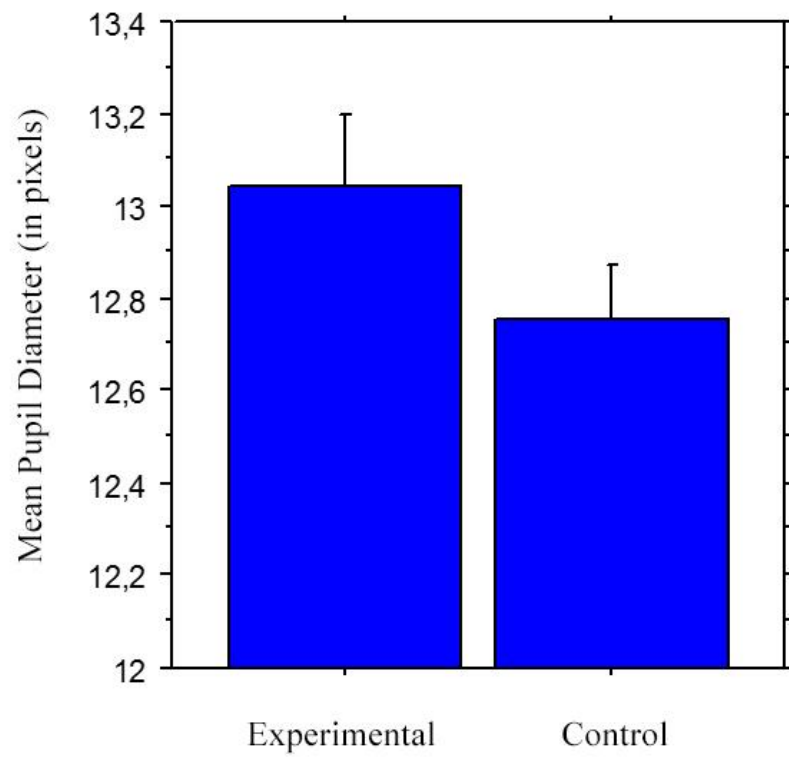


Figure 3. Mean pupil's size in pixels, in the experimental and control condition for all participants (N=52). Error bars represent ± 1 standard error.

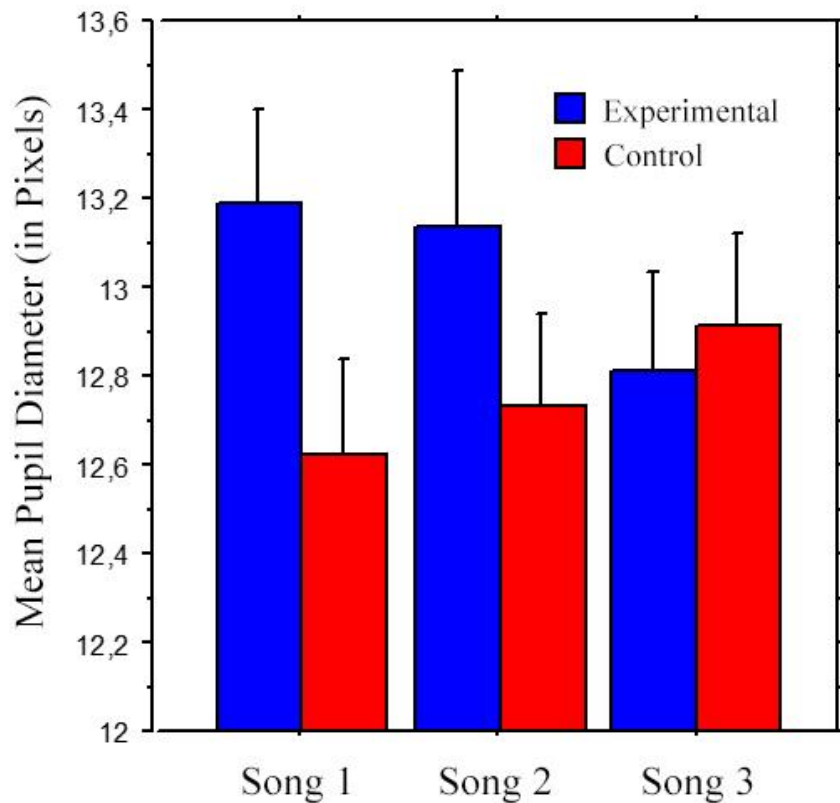


Figure 4. Pupil mean size in pixels for all participants, split between experimental and control condition and songs. Error bars represent ± 1 standard error.

Participants with number of chills above the median number of chills (i.e., ≥ 13) were selected from those with a low rate of chills. This group contained 28 participants, and it was separately analyzed in a repeated-measures ANOVA. Participants with chills under the median were excluded from the rest of the analysis. In fact, it seems more indicative to see the relationship between chills and psychological responses in those individuals who can clearly experienced music chills in the laboratory condition. The means and SDs of such selected “high chills” group are shown in Table 3. The results showed a significant effect for songs (experimental, control), $F(1,27) = 6.31$, $p < .02$. There was a significant interaction between Song*Condition, $F(2,54) = 8.77$, $p < .0005$. The pupils were more dilated in the experimental condition for experimental song 1 and 2, as seen in the analysis with all participants. A significant interaction was also found for response (active/passive) and songs (experimental, control), $F(1,54) = 12.06$, $p < .0017$, showing that the pupils dilated maximally to the experimental songs and in the active response condition. This is illustrated in figure 5.

Table 3

Mean pupil size presented in pixels for participants with median (Chill factor ≥ 13).

Song * Response * Condition	N	Mean	SD
Song 1, Active, Experimental	28	13.74	2.42
Song 1, Active, Control	28	12.65	2.46
Song 1, Passive, Experimental	28	13.35	2.12
Song 1, Passive, Control	28	12.74	2.17
Song 2, Active, Experimental	28	13.39	2.37
Song 2, Active, Control	28	12.90	2.70
Song 2, Passive, Experimental	28	13.00	1.99
Song 2, Passive, Control	28	13.11	2.05
Song 3, Active, Experimental	28	13.11	2.56
Song 3, Active, Control	28	13.26	2.61
Song 3, Passive, Experimental	28	12.86	2.38
Song 3, Passive, Control	28	13.28	1.89

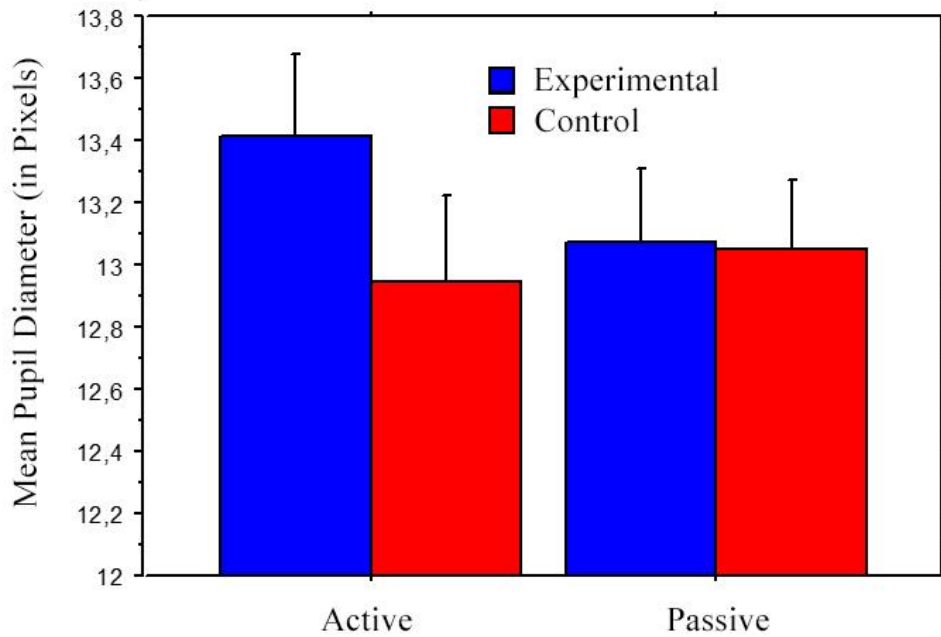


Figure 5. Pupil mean size in pixels for participants in the High Chills group only, and in both songs conditions and active versus passive listening. Error bars represent ± 1 standard error.

3.3 Pupils during chills

A repeated-measures ANOVA was also performed in order to investigate the pupils size during the actual time of chills for all participants ($N=45$). Six participants were excluded due to key presses in both conditions. The active key presses were then located only in each of the participants experimental songs, given that there was a very low rate of keypresses in the control condition. The active keypresses were compared to those within the same time windows in the same songs when listened passively. There was a significant effect of Song versus Baseline, $F(1,45)=33.68$, $p < .0001$, and response (active, passive), $F(1,45) = 18.33$, $p < .0001$. There were also a significant difference between Song versus Baseline and response (active, passive song and active, passive baseline), $F(1, 45) = 18.48$, $p < .0001$. The means and SDs for each participant are shown in Table 4. See Figure 6 for illustrations.

Other repeated-measures ANOVA were performed to compare the pupils during chills and for only those participants with a high rate of chills (i.e., a “chill factor” above the group’s median), which resulted in 24 of 28 participants, having excluded those participants who made key presses also in the passive condition. The mean and SDs for each participant

are shown in Table 5. There were significant main effects of ‘Songs versus Baseline’, $F(1,23)=8.92$, $p < .007$, and Response (active, passive), $F(1,23) = 9.53$, $p < .005$. There were also a significant interaction between ‘Songs versus Baseline’ and Response, $F(1,23) = 8.61$, $p < .007$ (see Figure 7). It is clear that baseline measurements yielded smaller pupils than when listening, especially compared to active listening.

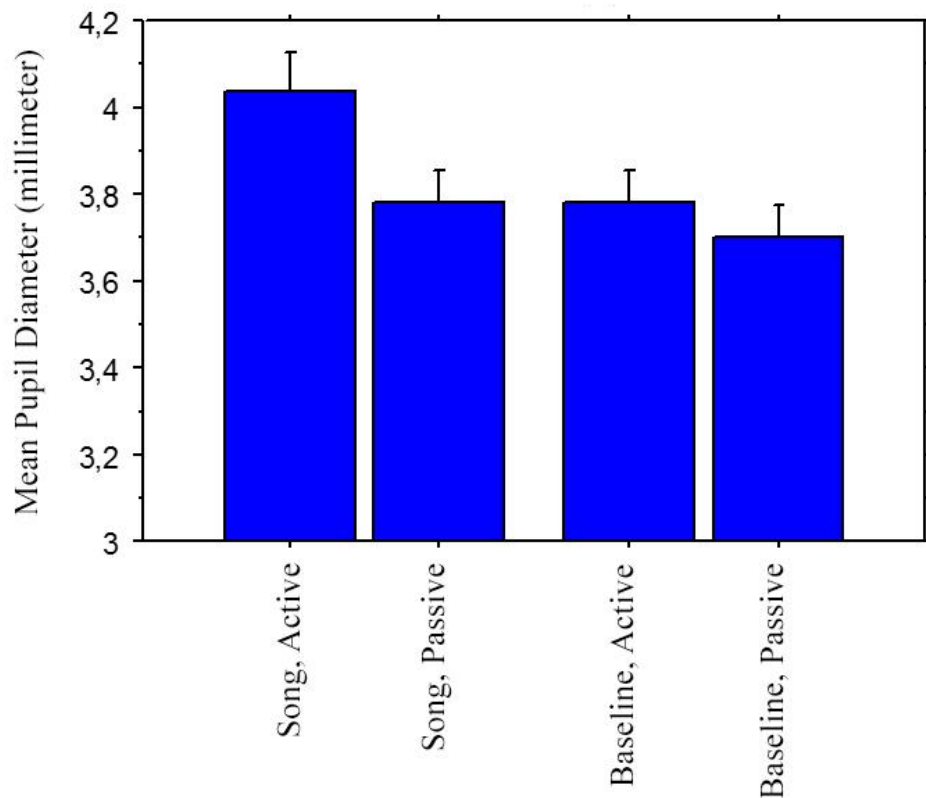


Figure 6. Mean pupil diameters in mm of all participants for songs and baseline conditions and active /passive listening. Error bars represent ± 1 standard error.

Table 4

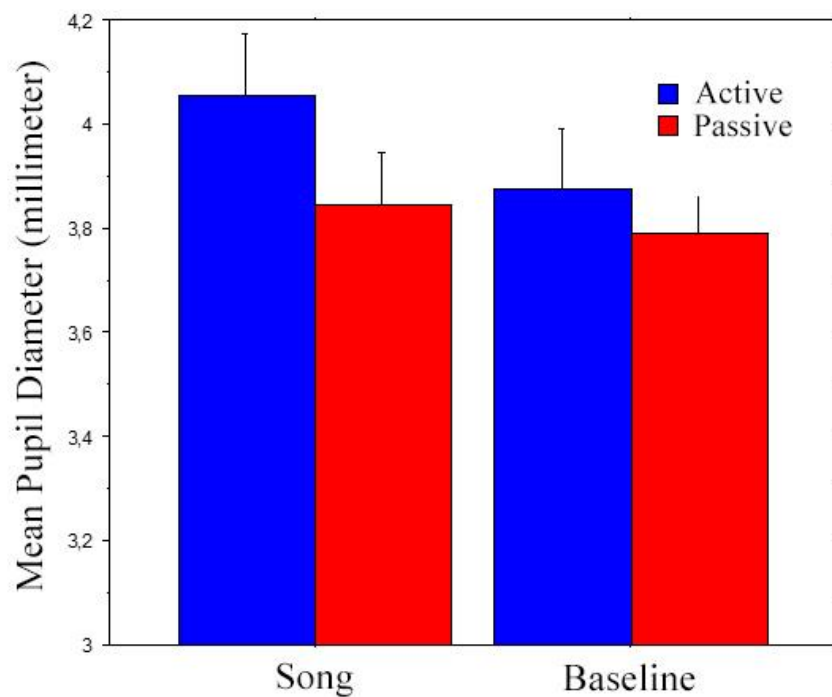
Effect: Chills*Response, with all participants.

	N	Mean	SD
Song, Active	46	4.03	.57
Song, Passive	46	3.78	.50
Baseline, Active	46	3.78	.52
Baseline, Passive	46	3.69	.51

Table 5

Effect: Chills Response for participants in the High Chills group.*

	N	Mean	SD
Song, Active	24	4.05	.588
Song, Passive	24	3.84	.518
Baseline, Active	24	3.87	.564
Baseline, Passive	24	3.79	.530



Figur 7. Mean pupil diameters in mm of participants in the High Chills group only, for songs and baseline conditions and active/passive listening. Error bars represent ± 1 standard error.

Finally, a repeated-measure ANOVA for only the passive-listening condition was performed to confirm the presence of different pupillary changes between the experimental songs and the control songs even when participants did not need to report the presence of chills or focus on their peak experiences. This analysis showed a significant difference between the experimental songs and control songs, $F(2,50) = 83.64$, $p < .03$. Separate ANOVAs were performed for each song in order to determine what difference caused the interactive effect with experience and in the expected direction. Only the ANOVA for the first

song showed a significantly higher pupil response for experimental songs than control ones, $F(1, 25) = 16.9$, $p = .0004$. The ANOVAs for Song 2 and 3 failed to show any reliable difference during this passive listening condition.

Finally, we performed regression analyses of mean pupil size during the same time window in the active versus passive listening conditions of the same song; this revealed that the pupils were strongly positively correlated, $R = .64$, $p < 0.001$ (Figure 8). This analysis suggests that similar physiological states took place in both conditions, whether an active response was made or not.

A similar regression analysis using instead the median pupil size in the active and passive conditions during the whole song also showed a positive relationship. The regression plot (see Figure 9) for Active Listening median versus Passive Listening median, $R = .75$, $p < .001$, shows even more clearly that the level of autonomic arousal in the two conditions was generally very similar, since these data ignored chill-related key presses.

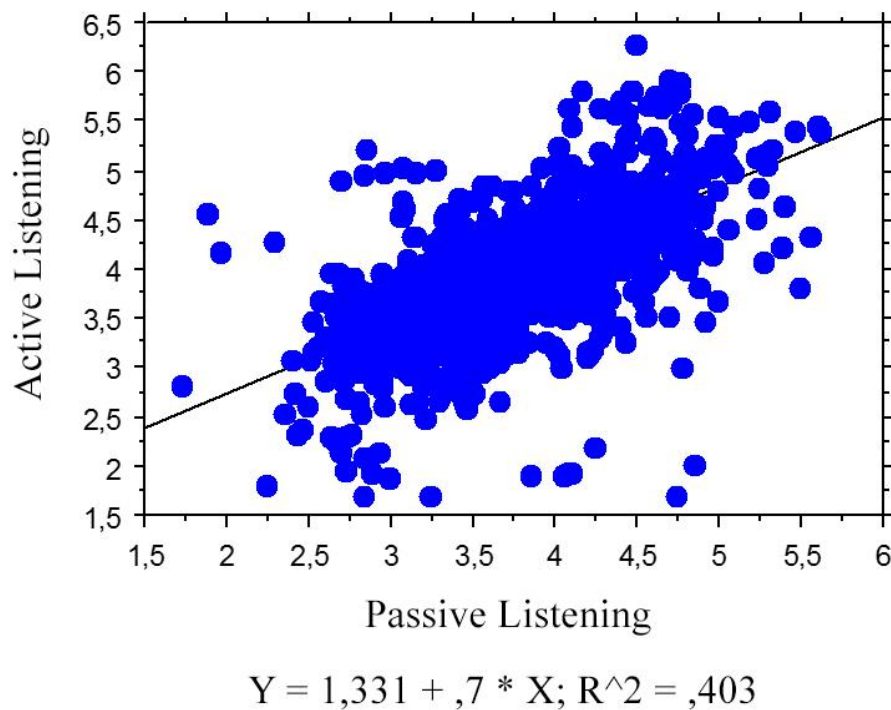


Figure 8. Regression plot (for the High Chills group) showing that active and passive listening for pupils within the chill related time window were positively correlated.

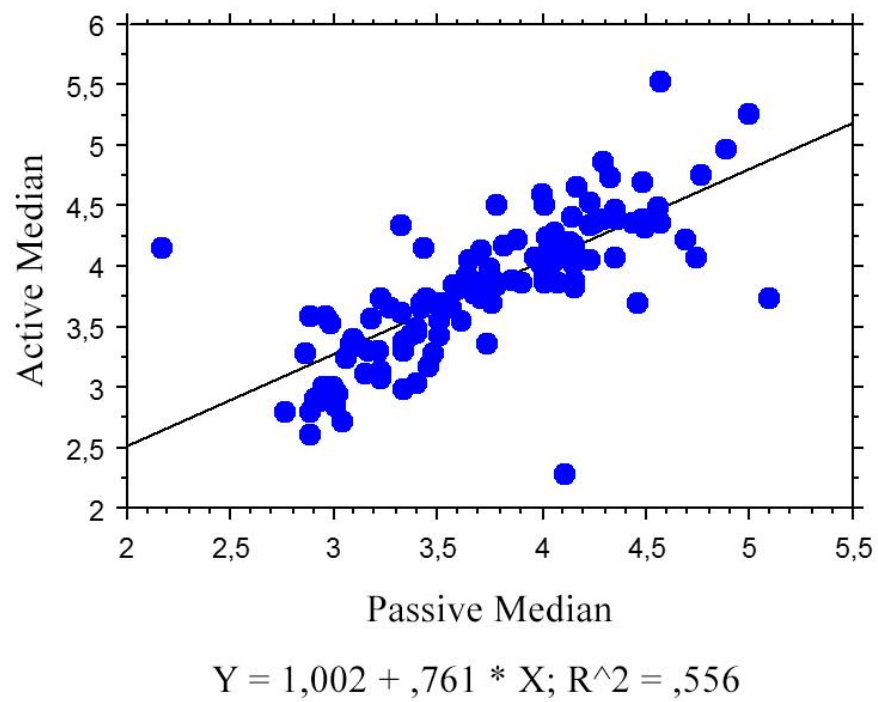


Figure 9. Regression plot (for the High Chills group) showing that the two variables, active and passive median of pupils within the chill related time window were positively correlated.

4 Discussion

The aim of this study was to investigate the relationship between pupil diameter and the experience of chills. To our knowledge, this is the first study to combine pupillometry with music chills. This may not be surprising, since music has measurable effects on behavior and brain chemistry, and, most intriguingly, also on the increased turnover of norepinephrine (NE) (Panksepp & Bernatzky, 2002). The present experiment was specifically designed to investigate pupillary responses during chills, because of the known relationship between the activation of the LC–NE modulatory system of the brain and changes in pupil size. We hypothesized that 1) Participants would respond more to their own selected songs than their control songs. 2) Participants' pupils would dilate around the time when they experience chills to their own chosen music, and 3) the increase in pupil size would be greatest around key presses that represent experienced chills.

When counting the number of chills by key presses for all participants, as expected, participants experienced more chill episodes to their own music choices than the control songs. This is in line with findings from previous studies (Panksepp, 1995; Blood and Zatorre, 2001). As mentioned in the introduction, Salimpoor et al. (2001) tested participants' control songs before the experimental testing, in order to select neutral songs for each participant. Despite this was not done in the present study, the findings showed a significant difference between the number of chills between the subject-selected songs and the control songs. The only criteria for the control songs were that they were chosen by a matched participant by sex and age. Most of the participants told the experimenter at debriefing that their control songs were something they would have not categorically selected, confirming that they were well suited as control songs. Another difference with the present study and that of Salimpoor et al. (2011) is that they asked their participants not to listen to the self-selected songs before the actual testing, to produce the maximum effect of chills.

An interesting finding in the analysis of pupils during chills was that the mean pupil size decreased with number of songs listened. In fact, during passive listening, the experimental condition yielded larger pupils than the control only for song 1. Similar results were found for a subgroup of participants that experienced high rate of chills. Although the pupils reacted more to all experimental songs, it is likely that fatigue or habituation may have influenced the response and the NE system may have become less reactive after listening to the first songs. It remains unclear if such a fatigue was induced by the unusual laboratory

conditions and by having to introspect on the experience; we also don't know if this habituation can be generalized to more ecological conditions (e.g., during a live performance).

The regression analysis of active versus passive listening for participants with high chill rate, showed that the pupil responses in the two conditions were strongly correlated. However, the active condition with key presses yielded significant results, for both the participants with high and low chill rates. The regression analysis of active versus passive median showed a strong relation between active and passive listening. Thus, the above findings suggest that participants would experience chills to their own chosen music regardless of whether they experienced many or few of them and regardless of whether they were asked to dwell on their experiences, by actively reporting them, or not. We also found a significant differences between the passive and active chill response versus baselines for all participants. As well as only participants with high chill rates.

As mentioned, in earlier research it has been found that there is a link between the pupillary response and activation of the LC - NE system (Laeng, Sirois, & Gredeback, 2012). Emotional contexts increased pupil dilation during successful retrieval of neutral events, and that increased pupil dilation correlates with LC activity. Neuroimaging shows that there is no significant LC activation during retrieval when there was no pupil diameter increase at learning (Sterpenich et al., 2006). The LC-NE system is important in memory retention (Sara, 2009) and emotional memories are better remembered than neutral ones (Sterpenich et al., 2006). Given that music is often linked to emotional memories, it seems important to show a link between the chill response and pupil size, as the latter can be used as an indirect marker of activity within the LC-NE system (Privitera et al., 2010).

Panksepp and Bernatzky (2002) had reasoned on the basis of animal studies that musical stimulation has measurable effects on increased turnover of norepinephrine (NE). Their idea is consistent with the findings in our study. In fact, the claim made by Harrison and Loui (2014) that chill responses are untestable other than through self-report, seems incorrect, since our participants' pupils were clearly correlated with the occurrence of chills in this study.

It is important to note that even during passive listening, we observed larger pupil diameters in the experimental condition, despite the participants did not have to give any explicit report. This finding is important in suggesting that chills do not occur only when a person must focus on the experience or when an explicit response is required (e.g., a key press). However, we observed that the pupils were sensitive to the order of the songs, with only the participant-selected song number 1, clearly showing the expected effect. This

indicate that after the first song, participants may have experienced fatigue or habituation or they had become depleted of the ability to have peak experiences. In fact, fatigue is known to cause pupil constriction (Lowenstein, Feinberg, & Loewenfeld, 1963).

Interestingly, Brown et al. (2004) found that passively listening to unfamiliar instrumental music can elicit strongly pleasant feelings in the same way as with familiar music.

4.1 Questionnaire

All participants answered a questionnaire before taking part in the experiment. Their answers showed no specific pattern. Specifically, there were no specific music genres that tended to yield chills more than any other. This can indicate that music can be effective for developing chills, and that it does not have to occur only for the music that is often accompanied, within a culture or with bodily activity (e.g., dance music, rock, or the foot tapping in jazz music). This ubiquity of chills in the music universe seems in line with what Silvia and Nusbaum (2011) found in their studies, where genre also didn't differ in provoking emotional responses.

There were no differences in age, between the sexes, or in their education. Remarkably, every participant had experienced chills in some form. The questionnaire and answers to the checklist in numbers, as well as the participant's answers to favorite music genres is shown in Appendix B and C.

4.2 Limitations

Despite the findings of this study seems compelling, there are clear limitations that need to be mentioned. The experiment lasted a long time and required a lot from the participants in terms of attending to the stimuli and fixating constantly on the screen and keeping the eyes open at all times. In fact, it may be easier to experience chills when people can close their eyes. This strong, protracted requirements may be unnatural and may have rapidly caused fatigue. The volume was set the same at the start of every experiment, and some of the participants requested higher volume in order to better feel the chills. Some participants also wanted lower volume. The volume has been found to influence the ability to get chills (Grewe et al., 2007). We tested people in the laboratory but it is likely that in ecological situations or at home or in a concert hall, one would experience chills more

liberally. In sum, our laboratory study may have greatly underestimated the occurrence of chills in music listening.

4.3 Implications for future work

Any single study, despite the quality of the evidence, warrants a replication of the findings in order to confidently conclude for an effect of chills on pupil responses and for self-chosen songs. It may also be beneficial, in a laboratory setting, to make the duration of the experiment shorter, or divide testing into shorter periods, allowing pauses. A larger sample size and variety of participants would also insure generalization of the present results.

Finally, given the likely implication of the norepinephrine system in music chills, it seems warrant to combine, in a future study, pupillometry and fMRI, ideally with participant-chosen songs versus control songs.

4.4 Conclusion

There is a relationship between pupil diameter and the experience of music chills, which suggests that music chills have measurable effects on both behavior and brain chemistry. The present findings strengthen the relationship between the activation of NE seen as changes in pupil size and chills. Chills are not exclusively measurable by self-reports, but also through correlated psychological measurements. It was unexpected that the order of the songs played such an important role, as well as the amount of time of the experience. Importantly, control songs never showed stronger effects than the experimental songs, which speaks for the subjective quality of the experience. The present results extend and support previous studies of chills and music.

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APPENDIX A

MUSIC CHILLS Questionnaire

Many people experience when they listen to some music an intense peak of pleasure, like a rapture and total absorption or focus in the musical moment. These feelings can also result in felt bodily reactions that may vary remarkably from person to person but that tend to reach peak intensity at precise moments during the musical listening.

These reactions can include weeping and/or skin sensations, like goose bumps or “chills” or “thrills”, and changes in the muscles of the body (e.g., shivers down the neck and back that may spread down the limbs and envelope one’s body) as well as in the muscles of the face (like a flow of relaxation). Some individuals can also feel their heartbeat change. One may feel merging into the music.

Below we ask some specific questions in order to understand the extent and frequency of your own experiences while listening to music that particularly “moves” you emotionally.

Translation to Norwegian:

Mange mennesker opplever med noen typer musikk et følelsesmessig klimaks og blir nærmest absorbert inn i det musikalske øyeblikket. Disse følelsene kan også resultere i en variasjon av fysiske reaksjoner. Selv om reaksjonene er individuelle, når de gjerne et klimaks ved spesifikke momenter under lyttingen.

Reaksjoner som kan dukke opp kan for eksempel være tårer / gråt, hudreaksjoner som ”gåsehud” og frysninger, spenning og forandringer i musklene. For eksempel kan man skjelve eller få frysninger som går fra nakke og nedover ryggraden, for så å spre seg rundt og ”pakke inn” hele kroppen, eller at man opplever total avslapning i ansiktsmusklene. Noen personer kan også føle endringer i hjerterytmen. Man kan føle at man går i ett med musikken.

Nedenfor stiller vi noen konkrete spørsmål for å forstå omfanget og frekvensen av dine egne opplevelser mens du hører på musikk som har en følelsesmessig innvirkning på deg.

We would like you to think about 3 musical pieces (e.g., a pop/rock song, a jazz ballad or a solo, a piano/violin sonata; you-name-it...) that you know are most effective, and can move you powerfully to the point of obtaining some of the peak experiences (we will call them “chills” hereafter), that we described above, or something close to it at the emotional level.

Please write the name of the musician and the song's title (if possible, please provide the address/link to the song/piece available on YouTube):

- 1) _____
- 2) _____
- 3) _____

We would also like to tell us how often you experienced the so-called “chills” while listening to music (please choose only 1 answer):

- Never had such an experience ☐
- It happened only once or twice, in special moments ☐
- It happens from time to time, given the right conditions ☐
- It happens often with a particular piece of music ☐
- It happens all the time with a particular piece of music ☐

Any comments to the above questions?

We would also like you to tell us if you have experienced one or several of the following experiences (you can choose multiple answers) when simply listening to music (in the absence of other activities or behaviors):

- I have wept ☐
- I felt a tremor in my body ☐
- I felt a tingling of the skin ☐
- I felt my hair standing ☐
- I felt a lump in my throat ☐
- I felt cold in my body ☐
- I felt it sexually pleasurable (almost like an orgasm) ☐
- I felt “one” with the music, enveloping everything ☐

Any comments to the above questions?

How often you choose to listen to music?

- Rarely (e.g., once a week) ☐

- Everyday



How long do you listen to the music (in hours)? _____

What is your favorite kind of music (name 3; e.g., classical, jazz, folk, etc.)?

Do you play any musical instrument/s? _____

If yes, how many hours a day? _____

Do you have synesthetic experiences (e.g., seeing colors or shapes moving, etc.)
related to music? _____

If anything above was unclear, please write your question/s here:

Your name: _____

Date of birth: _____

Your education: _____

Sex (please circle): ♀ ♂

Your email and/or telephone were to reach you:

APPENDIX B

We would also like to tell us how often you experienced the so-called “chills” while listening to music

Never had such an experience	0
It happened only once or twice, in special moments	1
It happens from time to time, given the right conditions	27
It happens often with a particular piece of music	18
It happens all the time with a particular piece of music	6

We would also like you to tell us if you have experienced one or several of the following experiences (you can choose multiple answers) when simply listening to music (in the absence of other activities or behaviors):

I have wept	31
I felt a tremor in my body	24
I felt a tingling of the skin	37
I felt my hair standing	40
I felt a lump in my throat	36
I felt cold in my body	16
I felt it sexually pleasurable (almost like an orgasm)	6
I felt “one” with the music, enveloping everything	29

APPENDIX C

Favorite music genres chosen by participants	
Blues	
Jazz	
- subcategories of jazz:	
	Gypsy, Happy, Jazz-rock
Classical	
Pop	
- subcategories of pop:	
	80`s, French, Melodious, Pop-rock
Hip Hop	
Rap	
Folk	
Indie	
Punk	
Slow	
Melancholy	
Ambient	
Rock	
- subcategories of rock:	
	Folk, Classical, 70`s, Progressive, Adult Oriented Rock, 80`s, Stoner, 1970s
	Doom, Glam, Jazz, Alternative
	Psychobilly
	Electronica
	Industrial
	Metal
- subcategories of Metal:	
	Extreme, Heavy, Atmospheric Black Metal, Progressive, Doom, Death,
	Black, Groove, Classic, Alternative
	Trance
- subcategories of trance:	

Uplifting, Orchestral, Emotional

R&B

Celtic

Film/TV Score

Musicals

Soul

Funk

Singer/ Songwriter

Agro Techno

Synth

Chill

World Music

African Highlife